TITLE

Differences in step characteristics and linear kinematics between rugby 1 players and sprinters during initial sprint acceleration

AUTHOR

Wild, James J.; Bezodis, Ian N.; North, Jamie S.; et al.

JOURNAL

European Journal of Sport Science

DATE DEPOSITED

12 June 2018

Article title: Differences in step characteristics and linear kinematics between rugby players and sprinters during initial sprint acceleration

Article type: Original paper

Authors: James J. WILD[1, 3], Ian N. BEZODIS[2], Jamie S. NORTH[3], & Neil E. BEZODIS[4]

Affiliations: [1]School of Biosciences and Medicine, University of Surrey, Guildford, Surrey, United Kingdom, GU2 7XH; [2]Cardiff School of Sport and Health Sciences, Cardiff Metropolitan University, Cyncoed Road, Cardiff, United Kingdom, CF23 6XD; [3]Expert Performance and Skill Acquisition Research Group, School of Sport, Health, and Applied Science, St Mary's University, Twickenham, United Kingdom, TW1 4SX; [4]Applied Sports, Technology, Exercise and Medicine Research Centre, Swansea University, Bay Campus, Crymlyn Burrows, Swansea, United Kingdom, SA1 8EN

Correspondence: J. J. Wild, School of Biosciences and Medicine, University of Surrey, Guildford, Surrey, United Kingdom, GU2 7XH; tel +44 (0) 1483 300800; email: j.wild@surrey.ac.uk; ORCHID ID: orcid.org/0000-0001-7762-4768

Abstract word count: 245

Text-only word count: 4292

No. of figures & tables: 3 figures, 1 table

Co-author details: I.N. Bezodis, Cardiff School of Sport and Health Sciences, Cardiff Metropolitan University, Cyncoed Road, Cardiff, United Kingdom, CF23 6XD; tel: +44 (0) 2920 41 7245; email: ibezodis@cardiffmet.ac.uk; ORCID ID: orcid.org/0000-0002-0250-032X

J.S. North, Expert Performance and Skill Acquisition Research Group, School of Sport, Health, and Applied Science, St Mary's University, Twickenham, United Kingdom, TW1 4SX; email: jamie.north@stmarys.ac.uk; tel: +44 2083404182; ORCID ID: orcid.org/0000-0003-2429-4552

N.E. Bezodis, Applied Sports, Technology, Exercise and Medicine Research Centre, Swansea University, Bay Campus, Crymlyn Burrows, Swansea, United Kingdom, SA1 8EN; email: n.e.bezodis@swansea.ac.uk; tel: +44 1792 295801; ORCID ID: orcid.org/0000-0003-2229-3310

Differences in step characteristics and linear kinematics between rugby players and sprinters during initial sprint acceleration

The initial steps of a sprint are important in team sports, such as rugby, where there is an inherent requirement to maximally accelerate over short distances. Current understanding of sprint acceleration technique is primarily based on data from track and field sprinters, although whether this information is transferable to athletes such as rugby players is unclear, due to differing ecological constraints. Sagittal plane video data were collected (240 Hz) and manually digitised to calculate the kinematics of professional rugby forwards (n = 15) and backs (n = 15), and sprinters (n = 18; 100m PB range = 9.96 s to 11.33 s) during the first three steps of three maximal sprint accelerations. Using a between-group research design, differences between groups were determined using magnitude based inferences, and within-group relationships between technique variables and initial sprint acceleration performance were established using correlation. Substantial between-group differences were observed in multiple variables. Only one variable, toe-off distance, differed between groups (d = -0.42 to -2.62) and also demonstrated meaningful relationships with sprint performance within all three groups (r = -0.44 to -0.58), whereby a stance foot position more posterior relative to the centre of mass at toe-off was associated with better sprint performance. Whilst toe-off distance appears to be an important technical feature for sprint acceleration performance in both sprinters and rugby players, caution should be applied to the direct transfer of other kinematic information from sprinters to inform the technical development of acceleration in team sports athletes.

Keywords: *biomechanics; constraints; rugby union; sprinting; technique*

Introduction

Sprint acceleration is an important performance feature in team sports such as rugby, where the typical sprint time is between one and three seconds (Deutsch, Kearney, & Rehrer, 2007; Roberts, Trewartha, Higgitt, El-Abd, & Stokes, 2008). However, the majority of the current understanding of acceleration technique is from studies of track and field sprinters (e.g. Bezodis, Salo, & Trewartha, 2014; Bezodis, Salo, & Trewartha, 2015; Debaere, Delecluse, Aerenhouts, Hagman, & Jonkers, 2013; Ettema, McGhie, Danielsen, Sandbakk, & Haugen, 2016; Jacobs & van Ingen Schenau, 1992; Mero, Luhtanen, & Komi, 1983; Morin et al., 2015; Nagahara, Matsubayashi, Matsuo, & Zushi, 2014; Rabita et al., 2015), and the techniques adopted by high performing sprinters have been used for the development of general technical models during the initial steps of a sprint (Mann & Murphy, 2015). This information is potentially attractive to coaches of athletes in team sports since it is based on the fastest of all athletes and may be used to help inform their players' sprint training practices. However, this approach implies that an ideal movement template exists for all athletes and does not take into account the differing movement strategies which may emerge from the interaction of divergent constraints imposed (Newell, 1986; Saltzman & Kelso, 1987).

The constraints thought to influence movement have been separated, by Newell (1986), into three distinct categories – task, environment and organismic (hereafter referred to as 'performer'). Variations in technique and movement patterns can therefore emerge between team sport athletes (such as rugby players) and sprinters as a function of differing interacting constraints (Davids, Button, & Bennett, 2008; Newell, 1986). Although the broad goal of maximal linear sprinting for sprinters and rugby players during the initial steps is the same (i.e. to cover as much distance in as short a time as possible), different task constraints exist due to sprint start conditions. The block exit (sprinters) and standing (rugby players) start conditions, for instance, require different body segment orientations which may influence techniques adopted in the subsequent steps. The environment in which each group performs also differs. For example, rugby is typically played on a grass surface, whereas sprinters compete on a running track. Rugby players are also required to sprint as one of many match demands in their training and competition environments. Differences in such demands are also further evident across playing position in rugby (i.e. forwards versus backs; Quarrie, Hopkins, Anthony, & Gill, 2013). Regarding performer constraints, movement strategies adopted between athlete groups are also likely to be affected by physical and anatomical constraints (Holt, 1998). Different performer constraints between sprinters and rugby players, such as physical stature and body mass, musculoskeletal structure (Lee & Piazza, 2009), and strength qualities may therefore result in different patterns of movement. It is therefore important to understand which, if any, of the technical features identified as important for sprint acceleration performance in a sprint-trained population may be useful to inform the practices of coaches in attempts to enhance the acceleration abilities of rugby players, given the differing constraints imposed.

There are likely many technical factors which influence initial sprint acceleration performance. In fact, spatiotemporal variables, including step length and step rate (the product of which determines step velocity) have received substantial attention in the literature (e.g. Debaere, Jonkers, & Delecluse, 2013; Lockie, Murphy, Schultz, Jeffriess, & Callaghan, 2013; Mackala, Fostiak, & Kowalski, 2015; Mann & Murphy, 2015; Mero, Luhtanen, & Komi, 1983; Murphy, Lockie, & Coutts, 2003; Nagahara, Naito, Morin, & Zushi, 2014; Rabita et al., 2015). Despite this coverage, there remain conflicting perspectives on the importance of step length and step rate during the initial steps of a sprint. For instance, in field sport athletes, higher step rates were reported during the first three steps for a faster group (time to 15 m) compared with a slower group (Murphy, Lockie, & Coutts, 2003), yet in 39 soccer players, running speeds over the first four steps of a sprint were positively correlated with average step length ($r = 0.60$; $p < 0.001$), but not average step rate (Nagahara, Takai, Kanehisa, & Fukunaga, 2018). Moreover, neither step length or step rate of sprinters were significantly correlated with 10 m sprint performance from a block start (Debaere, Jonkers, & Delecluse, 2013). In addition to these mixed findings, information on the determining factors of step length and step rate (Hay, 1994; Hunter, Marshall, & McNair, 2004) is also sparse.

Due to the limited information available during the initial steps and conflicting findings on the relative importance of step length and step rate to sprint performance, establishing the importance of specific technical features for sprint acceleration is currently challenging for a coach. This is further compounded by different measures used (e.g. absolute or relative), study designs adopted (e.g. correlations or group comparisons) and disparities between how acceleration performance is quantified, which may explain some of the contradictions (Bezodis, Salo, & Trewartha, 2010). Furthermore, due to the aforementioned inherent differences in the tasks, environments, and performer constraints of rugby players’ sprint acceleration compared with that of sprinters, the relevance of the available information on the technical features deemed important for performance in sprint-trained populations for enhancing the acceleration abilities of performers in team sports (e.g. rugby) is unknown. Therefore, a direct comparison between groups, with start conditions representative of their respective environments and standardised measures of the technical features of interest and sprint performance in the initial steps, is warranted. The purpose of this study was to investigate differences in step characteristics and linear kinematics between professional rugby players and sprinters during the initial steps of acceleration, and determine how each variable of interest relates to initial sprint performance within each group. We hypothesised that: 1) substantial differences in technique would be evident between sprinters and rugby players; 2) relationships between specific technique variables and initial sprint acceleration performance would be consistent across each group.

Methods

Participants

Eighteen male sprinters (mean ± *SD*: age 21 ± 4 years; stature 1.80 ± 0.10 m; body mass 75.7 ± 5.2 kg; 100 m personal best (PB) 10.60 ± 0.40 s, range 9.96 - 11.33 s) and 30 male professional rugby union players competing in the English Premiership, separated into forwards (n = 15; mean ± *SD*: age 25 ± 4 years; stature 1.88 ± 0.06 m; body mass 111.6 ± 8.9 kg) and backs (n = 15; mean ± *SD*: age 26 ± 4 years; stature 1.81 ± 0.06 m; body mass 88.6 ± 7.1 kg) volunteered to participate. All participants provided written informed consent and the study protocols were submitted to, and approved by, the Local Research Ethics Committee. At the time of testing, participants were injury free and completed maximal effort sprint accelerations on a weekly basis as part of their routine training. For the rugby players, data were collected during pre-season following 48 hours of abstinence from running, sprinting, and lower body strength training. For the sprinters, data were collected during track training sessions just prior to the competition phase of the outdoor season on days where the emphasis of training was to sprint maximally.

Procedures

The rugby players completed a 20 minute standardised warm-up, and then performed three maximal effort 10 m sprints from a standing start (preferred foot forward), on an outdoor acrylic surface, wearing a t-shirt, shorts and trainers, which was common during speed and acceleration training at the stage of pre-season when data was collected. Rest periods between each sprint were approximately 3-4 minutes. The sprinters completed their regular warm-up routine overseen by their technical coach, and then completed three maximal effort sprints over distances between 30 and 60 m from blocks, on an outdoor running track, wearing spikes, shorts and either a vest or no top. Rest periods between each sprint were between 7-12 minutes. Differences in the sprint performance measure between the first and third sprint trials within each group were less than the smallest worthwhile difference (d = < 0.20; Hopkins, 2002; Winter, Abt, & Nevill, 2014), thus the different rest period durations used by rugby players and sprinters did not bias any outcomes. For all sprints, video images (448 × 336 pixels) were obtained at 240 Hz (Sanyo Xacti VPC-HD2000). The camera was positioned 20 m from, and perpendicular to, the running lane to capture sagittal plane images from touchdown and toe-off across the first three steps for each athlete within an approximately 6 m wide field of view. A 5.00 m horizontal video calibration was recorded at each data collection session.

The kinematic variables of interest were determined from the video frames identified as the instants of touchdown (first frame the foot was visibly in contact with the ground) and toe-off (first frame the foot had visibly left the ground) across the first three steps of each sprint using 6× zoom in Kinovea (v.0.8.15). The human body was modelled as 14 rigid segments: feet, shanks, thighs, hands, lower arms, upper arms, trunk, and head. This required manual digitisation of the following: vertex of the head, halfway between the supra-sternal notch and the 7th cervical vertebra, shoulder, elbow and wrist joint centres, head of third metacarpal, hip, knee and ankle joint centres, the most posterior part of the heel, and the tip of the toe.

The scaled digitised coordinates were exported to Excel (Microsoft Office 2013), where the following spatiotemporal step characteristics were determined: contact time (s), flight time (s), step length (m; horizontal displacement between the toe tips at adjacent touchdowns), step rate (Hz; the reciprocal of step duration, which was determined as the sum of contact time and the subsequent flight time), and step velocity (m/s; the product of step length and step rate). Whole body centre of mass (CM) location was calculated using de Leva's (1996) segmental inertia data. This enabled the calculation of touchdown and toe-off distances (m; horizontal distance between the toe and whole body CM, with positive values representing the toe ahead of the CM), contact length (m; horizontal distance the CM travelled during stance) and flight length (m; horizontal distance the CM travelled during flight). All lengths and distances were normalised to stature. Finally, average horizontal external power was calculated, based on the change in kinetic energy as outlined by Bezodis et al. (2010), from the instant of the first touchdown until the end of the third contact phase, and used as an objective measure of sprint acceleration performance. In order to facilitate between-group comparisons, average horizontal external power was normalised according to a modification of the equation presented by Hof (1996) as used by Bezodis et al. (2010).

Statistical analyses

Test-retest intra-rater reliability of manual digitisation was determined using an intraclass correlation coefficient (ICC 3,1) with 90% confidence intervals. The segment endpoints at the instant of touchdown and toe-off, for ten participants selected at random, were digitised on two separate occasions, one week apart.

The data obtained for each kinematic variable were averaged across the three sprint trials of each participant. Differences between group means (sprinters, backs, and forwards) for all step characteristics and kinematic variables were analysed using a magnitude-based inference approach (Hopkins, Marshall, Batterham, & Hanin, 2009). Cohen's *d* (Cohen, 2013) was calculated between groups, with an effect size of 0.20 used to define the smallest worthwhile difference (Hopkins, 2002; Winter, Abt, & Nevill, 2014). The magnitudes of these standardised differences were expressed relative to the smallest worthwhile difference as follows: <0.2, trivial; 0.2, small; 0.6, moderate; 1.2, large; 2.0, very large and 4.0, extremely large (Hopkins et al., 2009). Confidence intervals (90%) were calculated to measure the uncertainty of the effect sizes, and the quantitative chances of finding between group differences in the variables tested greater than the smallest worthwhile difference were assessed as follows: 25 - < 75%, possibly; 75 - < 95% likely; 95 - < 99.5%, very likely; > 99.5%, most likely (Hopkins et al., 2009). If 90% confidence intervals included positive and negative values greater than the smallest meaningful difference (where the chances of positive and negative value differences are both >5%), the true difference was deemed unclear.

Each step characteristic and kinematic variable was then averaged over the first three steps for each participant. These values were used to determine the relationships of each technique variable with normalised average horizontal external power (NAHEP) within each group using Pearson's product moment correlation coefficient (r). Confidence intervals (90%) for the observed relationships were calculated to detect the smallest clinically important correlation coefficient. The magnitude of relationships were deemed unclear when confidence limits overlapped substantial positive and negative values (r = ± 0.1) (Hopkins, 2002). The strength of relationships were defined as (±): 0.35 (forwards and backs) and 0.31 (sprinters), unclear; 0.36 (forwards and backs) and 0.32 (sprinters) to 0.50 moderate; 0.50 to 0.70, high; 0.70 to 0.90, very high; 0.90 to 1.00, practically perfect (Hopkins, 2002).

Results

Intraclass correlation coefficients between the first and second digitising occasions indicated excellent (Portney & Watkins, 2000) intra-rater reliability for all step characteristics and kinematic variables (ICC >0.90; CL 0.85-0.99).

Regarding acceleration performance over the first three steps, backs most likely produced greater NAHEP than forwards, and the NAHEP of sprinters was most likely greater than the forwards and backs, the magnitude of these differences were extremely large and large, respectively (Figure 1). Of the spatiotemporal step characteristics, backs very likely achieved greater step velocities (Figure 2a) compared with forwards, the difference being moderate (*d* = 0.76 to 1.08; Table I). Sprinters very likely produced step velocities higher than forwards of moderate magnitudes (*d* = 0.95 to 1.18; Table I), although when compared with backs, the difference (in the same direction) was only possibly evident and small at the third step (*d* = 0.06 to 0.49; Table I).

****Figure 1 near here****

****Table I near here****

The step rates (Figure 2c) of backs were likely (step one) and very likely (steps two and three) greater than the forwards and of moderate magnitudes (*d* = 0.64 to 1.16; Table I). Sprinters possibly (step one) and likely (steps two and three) achieved greater step rates than the forwards. The magnitude of the differences were small and moderate, respectively (*d* = 0.28 to 0.77; Table I). However, the sprinters' step rates were possibly lower than those of the backs, with a small difference evident across all three steps (*d* = -0.46 to -0.32; Table I).

****Figure 2 near here****

The contact times (Figure 2d) of backs were likely shorter compared with forwards in step one (moderately) and very likely shorter in steps two and three, where the magnitudes of these differences were large and very large, respectively (*d* = -2.67 to -1.00; Table I). Sprinters' contact times were consistently shorter than forwards and longer than backs. Sprinters' contact times in the first step were possibly shorter (small magnitude), and by the second and third steps very likely and most likely shorter (moderate magnitudes), than those achieved by forwards (*d* = -1.89 to -0.47; Table I). Likely differences between sprinters' and backs' contact times were evident in step one (moderate magnitude) and possibly in steps two and three, of small magnitudes (*d* = 0.50 to 0.63; Table I).

The flight times (Figure 2e) of backs were possibly greater (moderate magnitude) during the first and second steps compared with forwards and likely greater (moderate magnitude) during the third step (*d* = 0.37 to 0.81; Table I). Differences in flight times between sprinters and forwards were likely (sprinters producing moderately greater flight times) for steps two and three (*d* = 0.13 to 0.76; Table I).

Backs likely produced greater step lengths (Figure 2b), which were moderately different compared with forwards during the first two steps and possibly longer step lengths of a small magnitude during step three (*d* = 0.51 to 0.75; Table I). Sprinters most likely produced longer step lengths compared with forwards and backs across each step. The magnitude of the differences were large (*d* = 1.36 to 1.46; Table I) relative to forwards, yet small and only possible in step one and moderate with likely differences in steps two and three in relation to backs (*d* = 0.52 to 0.92; Table I).

Backs' contact lengths (Figure 2f) were possibly smaller during steps one and three compared with forwards' (*d* = -0.25 and -0.33; Table I). Sprinters achieved contact lengths which were possibly shorter compared with forwards in step one and longer compared with backs in step three (*d* = -0.40 and 0.59; Table I). Backs likely achieved a greater flight length (moderate magnitude) compared with forwards during the first step and very likely greater flight lengths of moderate (step two) and large (step three) magnitudes (d = 0.87 to 1.63; Table I). The flight lengths of sprinters were most likely greater compared with forwards across all steps (*d* = 1.41 to 2.45; Table I). Sprinters' flight distance was also greater compared with backs where possibly and likely differences of small magnitudes were evident (*d* = 0.38 to 0.48; Table I).

Backs touched down with their toe more posterior to their CM than forwards across each step (Figure 2h). During step one they were possibly different (moderate magnitude), whereas the difference was likely and most likely during steps two and three (large magnitude), respectively (*d* = -1.19 to -0.57; Table I). Sprinters' touchdown distances (Figure 2h) were consistently more posterior across all steps relative to forwards and backs. The difference was most likely large (step one) and very large (steps two and three) compared with forwards (*d* = -2.64 to -1.92; Table I). Compared with backs, the differences were most likely and large in magnitude (step one), very likely and moderate in magnitude (step two), and likely and moderate in magnitude (step three; *d* = -0.89 to -1.69; Table I).

At toe-off backs possibly (steps one and three) and most likely (step two) positioned their toe more posterior relative to their CM position (Figure 2i) compared with forwards (d = -1.22 to -0.42). The magnitude of this difference was small in steps one and three and moderate in the second step. Sprinters most likely positioned their toe more posterior relative to their CM at toe-off compared with forwards and backs, where the difference was very large in each step (*d* = -2.62 to -2.05).

Regarding correlation coefficients, only toe-off distance consistently demonstrated a meaningful relationship with NAHEP in each group (Figure 3h), the magnitude of which was moderate for backs and large for forwards and sprinters (r = -0.58 to -0.44). Moderate relationships were also observed between step length and NAHEP (Figure 3a) in both forwards and sprinters (r = 0.39 and 0.45, respectively). In the same two groups negative relationships between contact time and NAHEP (Figure 3c) were observed (r = - 0.39 and r = - 0.35, respectively). The step rate of sprinters was moderately positively correlated to horizontal NAHEP (r = 0.44; Figure 3b), as was the contact length (r = 0.46; Figure 3e) of forwards.

****Figure 3 near here****

Discussion

The purpose of this study was to investigate the differences in step characteristics and linear kinematics between professional rugby players and sprinters during the initial steps of acceleration, and how each of these variables relates to initial sprint performance. This provides information to enhance the understanding of how knowledge of sprinters' acceleration techniques may be transferred to inform training practices aimed at enhancing the acceleration abilities of rugby players. The main finding of this study was that there were multiple differences in the magnitudes of various touchdown and toe-off kinematics between sprinters and rugby groups, confirming our first hypothesis. However, only one technical feature (toe-off distance) was consistently related to sprinting performance in all groups, and thus our second hypothesis was largely rejected. There may therefore be limitations in how the available information concerning the touchdown and toe-off kinematics and step characteristics of sprinters can be used by coaches tasked with enhancing the acceleration abilities of rugby players, possibly due to the different constraints imposed (Newell, 1986).

Sprinters achieved substantially greater levels of performance (NAHEP) compared with forwards and backs, by 40% and 19%, respectively. This is explained by their greater change in velocity from the beginning of the first contact phase to the end of the third (sprinters = 3.26 ± 0.28 m/s; backs = 2.60 ± 0.26 m/s; forwards = 2.48 ±0.28 m/s), since less than 0.03 s separated the groups with respect to the time taken to achieve this change. However, no substantial differences in absolute step velocity were found between sprinters and backs until step three, where sprinters possibly reached a higher step velocity (d = 0.49), because the backs entered the first step with a higher velocity than the sprinters (3.61 ± 0.16 vs. 3.36 ± 0.31 m/s; forwards = 3.38 ± 0.26 m/s). This is likely reflective of the differences in start conditions, where a longer distance between the feet in the standing start may lead to a longer push-off phase (Salo & Bezodis, 2004), thus affording the opportunity to produce higher impulse where the rapid initiation of a sprint in response to an external stimulus (e.g. starter’s gun) is not required.

Sprinters consistently produced longer step lengths than backs, who also achieved longer step lengths than forwards (Figure 2b), whilst backs achieved the highest step rates in each step, followed by sprinters and then forwards (Figure 2c). The inconsistent findings of previous research as to the relative contribution of step length and step rate to initial sprint acceleration performance (Debaere et al., 2013; Mackala, Fostiak, & Kowalski, 2015; Murphy et al., 2003) is further compounded by the results of the current study where positive moderate relationships of step length and step rate with NAHEP in sprinters were found (r = 0.45 and 0.44), whereas only step length was correlated to the NAHEP of forwards (r = 0.39) and no meaningful relationships of step length or step rate with the NAHEP of backs were found (Figures 3a; 3b).

The differences in step length between groups were achieved primarily through different flight lengths, but not contact lengths (Figure 2; Table I). However, the location of the foot relative to the CM position was more posterior at both touchdown and toe-off for sprinters compared with both rugby groups, and for backs compared with forwards (Figures 2h; 2i). Smaller touchdown distances have been shown to be related to a more forward-orientated ground reaction force (GRF) vector (Bezodis, Trewartha, & Salo, 2015; Kugler & Janshen, 2010), which has been identified as a key determinant of acceleration performance (Kawamori, Nosaka, & Newton, 2013; Kugler & Janshen, 2010; Morin, Edouard, & Samozino, 2011; Morin et al., 2012). However, no meaningful relationships between touchdown distance and NAHEP were evident in any group in the current study, which may be explained by a number of factors. For example, Bezodis et al. (2015) demonstrated the existence of a within-individual curvilinear relationship between touchdown distance and NAHEP in the first stance phase for an international–level sprinter, whilst vertical impulse production was found to increase linearly as the foot was placed further forward relative to the CM . Limiting how far posteriorly the foot makes contact relative to the CM may therefore be important in producing sufficient vertical GRF to support bodyweight. Consequently, an optimal touchdown distance is likely to exist for each individual influenced by varying constraints. For instance, greater vertical GRF will need to be produced with increased body mass, therefore potentially requiring a greater touchdown distance (i.e. foot positioned further forward of the CM). Additionally, the block start already positions the sprinter's CM ahead of their feet (Mero, Luhtanen, & Komi, 1983) and the effect of both running shoe worn and surface may also provide different opportunities for a sprinter's maintenance of balance. The range of different constraints imposed on rugby players (e.g. greater mass (performer constraint), standing start (task constraint), grass surface (environmental constraint)) suggest that expecting them to touch down posterior to their CM in the same manner as sprinters during the initial steps may not be feasible. It may also be possible to manipulate GRF orientation through other technical adjustments which combine to not affect the overall touchdown distance (Bezodis, North, & Razavet, 2017). Further investigations of segmental and joint angular kinematics during the initial steps of rugby players and how these are influenced by performer constraints such as physical qualities (e.g. strength, anthropometrics), as well as how they influence GRF orientation, may provide further insight into factors which influence rugby players' sprint acceleration technique and performance.

Whilst touchdown distance was not related to sprint performance for any of the groups, toe-off distance consistently was (r = -0.44 to -0.58). Having the stance toe further behind the CM at toe-off was associated with increased NAHEP in all three groups, and therefore appeared to be reflective of an effective push-off. A more negative toe-off distance was also evident in sprinters compared with backs, who in turn achieved more negative toe-off distances compared with forwards. The importance of this technical feature does appear to transfer between sprinters and rugby players and a CM further forward relative to the point of contact at toe-off during the first step has previously been associated with higher propulsive impulse (Kugler & Janshen, 2010).

Toe-off distance, and the body segment rotations used to achieve a greater toe-off distance may be representative of an effective 'push-off' and therefore a function of GRF orientation characteristics (Rabita et al., 2015), therefore warranting further investigation. In the current study, sprinters produced longer contact times relative to backs and may have used this to achieve a greater toe-off distance as a result (Kugler & Janshen, 2010). While start position and footwear may again play roles in the ability to achieve such a forward lean position, performer constraints may also be an important consideration. For example, Lee and Piazza (2009) demonstrated, through computer simulation, that the longer toes of sprinters (compared with non-sprinters) prolonged the time of contact during a 'push-off' giving greater time for forward acceleration by producing greater propulsive forces. However, it is possible to have a high impulse by pushing-off for longer, but low acceleration if the magnitude of the impulse (and thus change in velocity) is achieved primarily through spending a longer time generating GRF rather than by generating greater GRF magnitudes. This may account for the strategy of backs to produce higher step rates through shorter contact times whilst still achieving superior sprint performance compared with forwards.

This study aimed to quantify the differences in step characteristics and linear kinematics between professional rugby players and sprinters during the initial steps of acceleration, and determine how each technique variable related to the initial sprint performance of each group. Although we did not experimentally test each different ecological constraint independently, the groups were observed in representative settings to determine between group differences in their habitual environments. Therefore the findings are relevant to practitioners working with rugby players to enhance initial sprint acceleration performance. There were clear differences in touchdown and toe-off kinematics between groups which are likely to have emerged, at least in part, as a result of inherent differences in task, environment and performer constraints. Toe-off distance was the only technical feature to differ between the groups which was also consistently related to sprint performance within each group, and thus may be an important consideration which can transfer to the sprint training practices of rugby players. Other features of technique identified as potentially important for sprint acceleration performance from the existing literature on sprint-trained athletes may not transfer directly to rugby players.

References

Bezodis, N. E., Salo, A. I., & Trewartha, G. (2010). Choice of sprint start performance measure affects the performance-based ranking within a group of sprinters: Which is the most appropriate measure? *Sports Biomechanics, 9*(4), 258-269. doi:10.1080/14763141.2010.538713

Bezodis, N. E., North, J. S., & Razavet, J. L. (2016). Alterations to the orientation of the ground reaction force vector affect sprint acceleration performance in team sports athletes. *Journal of Sports Sciences,* 1-8. doi:10.1080/02640414.2016.1239024

Bezodis, N. E., Salo, A. I. T., & Trewartha, G. (2014). Lower limb joint kinetics during the first stance phase in athletics sprinting: Three elite athlete case studies. *Journal of Sports Sciences, 32*(8), 738-746. doi:10.1080/02640414.2013.849000

Bezodis, N. E., Salo, A. I. T., & Trewartha, G. (2015). Relationships between lower-limb kinematics and block phase performance in a cross section of sprinters. *European Journal of Sport Science, 15*(2), 118-124. doi:10.1080/17461391.2014.928915

Bezodis, N. E., Trewartha, G., & Salo, A. I. T. (2015). Understanding the effect of touchdown distance and ankle joint kinematics on sprint acceleration performance through computer simulation. *Sports Biomechanics, 14*(2), 232-245. doi:10.1080/14763141.2015.1052748

Cohen, J. (2013). *Statistical power analysis for the behavioral sciences* (2nd ed.). GB: Routledge Ltd. doi:10.4324/9780203771587

Davids, K., Button, C., & Bennett, S. (2008). *Dynamics of skill acquisition*. Champaign, IL [u.a.]: Human Kinetics.

de Leva, P. (1996). Adjustments to zatsiorsky-seluyanov's segment inertia parameters. *Journal of Biomechanics, 29*(9), 1223-1230. doi:0021929095001786

Debaere, S., Jonkers, I., & Delecluse, C. (2013). The contribution of step characteristics to sprint running performance in high-level male and female athletes. *Journal of Strength and Conditioning Research, 27*(1), 116-124. doi:10.1519/JSC.0b013e31825183ef

Debaere, S., Delecluse, C., Aerenhouts, D., Hagman, F., & Jonkers, I. (2013). From block clearance to sprint running: Characteristics underlying an effective transition. *Journal of Sports Sciences, 31*(2), 137-149. doi:10.1080/02640414.2012.722225

Deutsch, M. U., Kearney, G. A., & Rehrer, N. J. (2007). Time - motion analysis of professional rugby union players during match-play. *Journal of Sports Sciences, 25*(4), 461-472. doi:771195102

Ettema, G., McGhie, D., Danielsen, J., Sandbakk, O., & Haugen, T. (2016). On the existence of step-to-step breakpoint transitions in accelerated sprinting. *Plos One, 11*(7), e0159701. doi:10.1371/journal.pone.0159701

Hay, J. (1994). *The biomechanics of sports techniques* (4th ed.). London: Prentice Hall International.

Hof, A. L. (1996). Scaling gait data to body size. *Gait & Posture, 4*(3), 222-223. doi:10.1016/0966-6362(95)01057-2

Holt, K. (1998). Constraints in the emergence of preferred locomotory patterns. In D. Rosenbaum, & C. Collyer (Eds.), *Timing of behavior: Neural, psychological and computational perspectives* (pp. 261-292)

Hopkins, W. (2002). A scale of magnitudes for effect statistics. Retrieved from http://www.sportsci.org/resource/stats/effectmag.html

Hopkins, W., Marshall, S., Batterham, A., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise, 41*(1), 3-13. doi:10.1249/MSS.0b013e31818cb278

Hunter, J. P., Marshall, R. N., & McNair, P. J. (2004). Interaction of step length and step rate during sprint running. Medicine and Science in Sports and Exercise, 36(2), 261-271. doi:10.1249/01.MSS.0000113664.15777.53

Jacobs, R., & van Ingen Schenau, G. (1992). Intermuscular coordination in a sprint push-off. *Journal of Biomechanics, 25*(9), 953-965. doi:0021-9290(92)90031-U

Kawamori, N., Nosaka, K., & Newton, R. U. (2013). Relationships between ground reaction impulse and sprint acceleration performance in team sport athletes. *Journal of Strength and Conditioning Research, 27*(3), 568-573. doi: 10.1519/JSC.0b013e318257805a

Kugler, F., & Janshen, L. (2010). Body position determines propulsive forces in accelerated sprinting. *Journal of Biomechanics, 43*, 343-348. doi: 10.1016/j.jbiomech.2009.07.041

Lee, S. S. M., & Piazza, S. J. (2009). Built for speed: Musculoskeletal structure and sprinting ability. *Journal of Experimental Biology, 212*(22), 3700-3707. doi:10.1242/jeb.031096

Lockie, R. G., Murphy, A., Schultz, A. B., Jeffriess, M. D., & Callaghan, S. J. (2013). Influence of sprint acceleration stance kinetics on velocity and step kinematics in field sport athletes. *Journal of Strength and Conditioning Research, 27*(9), 2494-2503. doi:10.1519/JSC.0b013e31827f5103

Mackala, K., Fostiak, M., & Kowalski, K. (2015). Selected determinants of acceleration in the 100m sprint. *Journal of Human Kinetics, 45,* 135-148. doi:10.1515/hukin-2015-0014

Mann, R., & Murphy, A. (2015). *The mechanics of sprinting and hurdling*. Las Vegas: CreateSpace.

Mero, A., Luhtanen, A., & Komi, P. (1983). A biomechanical study of the sprint start. *Scandinavian Journal of Sports Sciences, 5,* 20-28.

Morin, J., Bourdin, M., Edouard, P., Peyrot, N., Samozino, P., & Lacour, J. R. (2012). Mechanical determinants of 100-m sprint running performance. *European Journal of Applied Physiology, 112*(11), 3921-3930. doi:10.1007/s00421-012-2379-8

Morin, J., Edouard, P., & Samozino, P. (2011). Technical ability of force application as a determinant factor of sprint performance. *Medicine and Science in Sports and Exercise, 43*(9), 1680-1688. doi:10.1249/MSS.0b013e318216ea37

Morin, J., Slawinski, J., Dorel, S., de villareal, E. S., Couturier, A., Samozino, P., Brugheli, M., Rabita, G. (2015). Acceleration capability in elite sprinters and ground impulse: Push more, brake less? *Journal of Biomechanics, 48*(12), 3149-3154. doi:10.1016/j.jbiomech.2015.07.009

Murphy, A. J., Lockie, R. G., & Coutts, A. J. (2003). Kinematic determinants of early acceleration in field sport athletes. *Journal of Sports Science & Medicine, 2*(4), 144-150.

Nagahara, R., Matsubayashi, T., Matsuo, A., & Zushi, K. (2014). Kinematics of transition during human accelerated sprinting. *Biology Open, 3*(8), 689-699. doi:10.1242/bio.20148284

Nagahara, R., Naito, H., Morin, J. B., & Zushi, K. (2014). Association of acceleration with spatiotemporal variables in maximal sprinting. *International Journal of Sports Medicine, 35*(9), 755-761. doi:10.1055/s-0033-1363252

Newell, K. (1986). Constraints on the development of coordination. In Wade, M and Whiting, H (Ed.), *Motor development in children: Aspects of coordination* (pp. 341-361). Amsterdam: Martinus Nijhoff Publishers.

Portney, L., & Watkins, M. (2000). *Foundations of clinical research: Applications to practice* (3rd ed.). New Jersey: Prentice Hall.

Quarrie, K. L., Hopkins, W. G., Anthony, M. J., & Gill, N. D. (2013). Positional demands of international rugby union: Evaluation of player actions and movements. Journal of Science and Medicine in Sport, 16(4), 353-359. doi:10.1016/j.jsams.2012.08.005

Rabita, G., Dorel, S., Slawinski, J., Saez-de-Villarreal, E., Couturier, A., Samozino, P., & Morin, J. B. (2015). Sprint mechanics in world-class athletes: A new insight into the limits of human locomotion. *Scandinavian Journal of Medicine & Science in Sports, 25*(5), 583-594. doi:10.1111/sms.12389

Roberts, S. P., Trewartha, G., Higgitt, R. J., El-Abd, J., & Stokes, K. A. (2008). The physical demands of elite english rugby union. *Journal of Sports Sciences, 26*(8), 825-833. doi:10.1080/02640410801942122

Salo, A., & Bezodis, I. (2004). Which starting style is faster in sprint running--standing or crouch start? *Sports Biomechanics, 3*(1), 43-53. doi:10.1080/14763140408522829

Saltzman, E., & Kelso, J. (1987). Skilled actions: a task-dynamic approach. *Psychological Review, 94*(1), 84-106.

Winter, E., Abt, G., & Nevill, A. (2014). Metrics of meaningfulness as opposed to sleights of significance. *Journal of Sports Sciences, 32*(10), 901-902. doi:10.1080/02640414.2014.895118

Tables

Table I. Effect sizes[a] (and their 90% confidence limits) for spatiotemporal step characteristics in each step between rugby backs and forwards, sprinters and rugby forwards, and sprinters and rugby backs.

	Backs vs. forwards					
	Step 1		Step 2		Step 3	
Spatiotemporal step characteristics	ES	90% CL	ES	90% CL	ES	90% CL
Step velocity (m/s)	1.08	0.52 to 1.65	0.92	0.43 to 1.41	0.76	0.22 to 1.31
Step rate (Hz)	0.64	0.11 to 1.17	1.45	0.52 to 2.38	1.16	0.51 to 1.81
Contact time (s)	-1.00	-1.54 to -0.46	-2.67	-3.37 to -1.97	-1.69	-2.21 to -1.16
Flight time (s)	0.37	-0.27 to 1.02	0.63	-0.11 to 1.38	0.81	0.03 to 1.58
Step length[b]	0.70	0.03 to 1.38	0.75	0.20 to 1.31	0.51	-0.08 to 1.11
Contact length[b]	-0.25	-0.80 to 0.30	0.12	-0.44 to 0.68	-0.33	-0.84 to 0.18
Flight length[b]	0.87	0.20 to 1.54	1.06	0.28 to 1.83	1.63	0.82 to 2.43
Touchdown distance[b]	-0.57	-1.10 to -0.03	-1.04	-1.74 to -0.34	-1.19	-1.76 to -0.61
Toe-off distance[b]	-0.56	-1.14 to 0.02	-1.22	-1.72 to -0.72	-0.42	-0.91 to 0.08
	Sprinters vs. forwards					
	Step 1		Step 2			
	ES	90% CL	ES	90% CL	ES	90% CL
Step velocity (m/s)	1.18	0.54 to 1.83	0.95	0.40 to 1.51	1.18	0.65 to 1.71
Step rate (Hz)	0.28	-0.21 to 0.77	0.71	0.06 to 1.37	0.77	0.21 to 1.34
Contact time (s)	-0.47	-0.97 to 0.03	-1.89	-2.87 to -0.92	-1.31	-1.81 to -0.81
Flight time (s)	0.37	-0.27 to 1.02	0.70	0.10 to 1.30	0.76	0.20 to 1.32
Step length[b]	1.36	0.78 to 1.94	1.41	0.85 to 1.96	1.46	0.87 to 2.04
Contact length[b]	-0.4	-0.89 to 0.08	0.02	-0.61 to 0.64	0.09	-0.42 to 0.61
Flight length[b]	1.41	0.71 to 2.10	1.64	1.04 to 2.23	2.45	1.80 to 3.10
Touchdown distance[b]	-1.92	-2.40 to -1.44	-2.64	-3.41 to -1.87	-2.03	-2.66 to -1.41
Toe-off distance[b]	-2.53	-3.12 to -1.94	-2.62	-3.20 to -2.05	-2.05	-2.67 to -1.43
	Sprinters vs. backs					
	Step 1		Step 2		Step 3	
	ES	90% CL	ES	90% CL	ES	90% CL
Step velocity (m/s)	0.11	-0.57 to 0.78	0.06	-0.68 to 0.80	0.49	-0.07 to 1.05
Step rate (Hz)	-0.46	-0.99 to 0.07	-0.38	-0.87 to 0.12	-0.32	-0.85 to 0.20
Contact time (s)	0.63	0.10 to 1.16	0.58	-0.19 to 1.34	0.50	-0.05 to 1.05
Flight time (s)	-0.21	-0.80 to 0.39	0.04	-0.47 to 0.55	-0.03	-0.51 to 0.46
Step length[b]	0.52	-0.01 to 1.04	0.76	0.17 to 1.36	0.92	0.35 to 1.50
Contact length[b]	-0.18	-0.69 to 0.33	-0.11	-0.78 to 0.56	0.59	0.00 to 1.18
Flight length[b]	0.42	-0.18 to 1.03	0.38	-0.13 to 0.88	0.48	-0.03 to 0.99
Touchdown distance[b]	-1.69	-2.20 to -1.18	-1.18	-1.82 to -0.55	-0.89	-1.53 to -0.25
Toe-off distance[b]	-2	-2.60 to -1.41	-2.16	-2.90 to -1.42	-1.71	-2.21 to -1.20

[a]A positive/negative effect size depicts a greater/lesser magnitude of spatiotemporal step characteristics produced by the first group in their respective group comparison (e.g. a positive effect size under 'Backs vs. forwards' for step velocity would indicate that backs produced a higher step velocity compared with forwards in that step). The magnitude of differences (Cohen's d) were expressed as: <0.20, trivial; 0.20 to 0.59, small; 0.60 to 1.19, moderate; 1.20 to 1.99, large; 2.0 to 3.99, very large; ≥ 4.0, extremely large.

[b]Normalised to participant's stature.

Figures

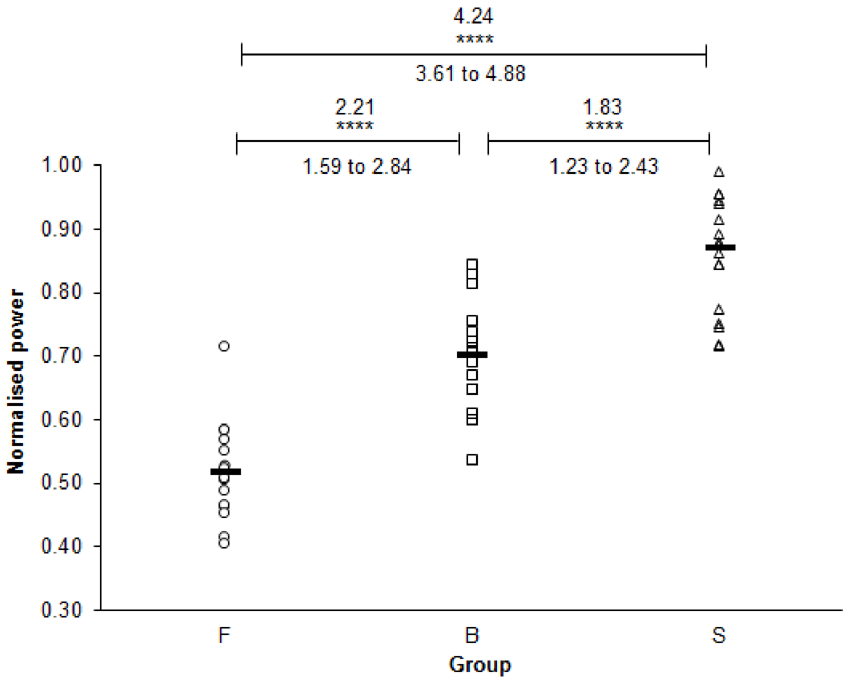

Figure 1. Normalised average horizontal external power[a] for forwards (F), backs (B) and sprinters (S) from first touchdown until the end of the third contact phase of a sprint, and the effect sizes[b] (and their 90% confidence limits[c]) between each group. Individual participant means are plotted, and the black bars represent group means. The number of asterisks depict the quantitative chances of finding between group differences: * = possibly; ** = likely, *** = very likely, **** = most likely.

[a]Normalised according to a modification of the equation presented by Hof (1996) as used by Bezodis et al. (2010).

[b]Above the asterisks. A positive/negative effect size depicts a greater/lesser magnitude of normalised average horizontal external power produced by the first group in their respective group comparison (e.g. a positive effect size under 'Backs vs. forwards' would indicate that backs produced higher normalised average horizontal external power compared with forwards). The magnitude of differences (Cohen's d) were expressed as: <0.20, trivial; 0.20 to 0.59, small; 0.60 to 1.19, moderate; 1.20 to 1.99, large; 2.0 to 3.99, very large; ≥ 4.0, extremely large.

[c]Below the asterisks.

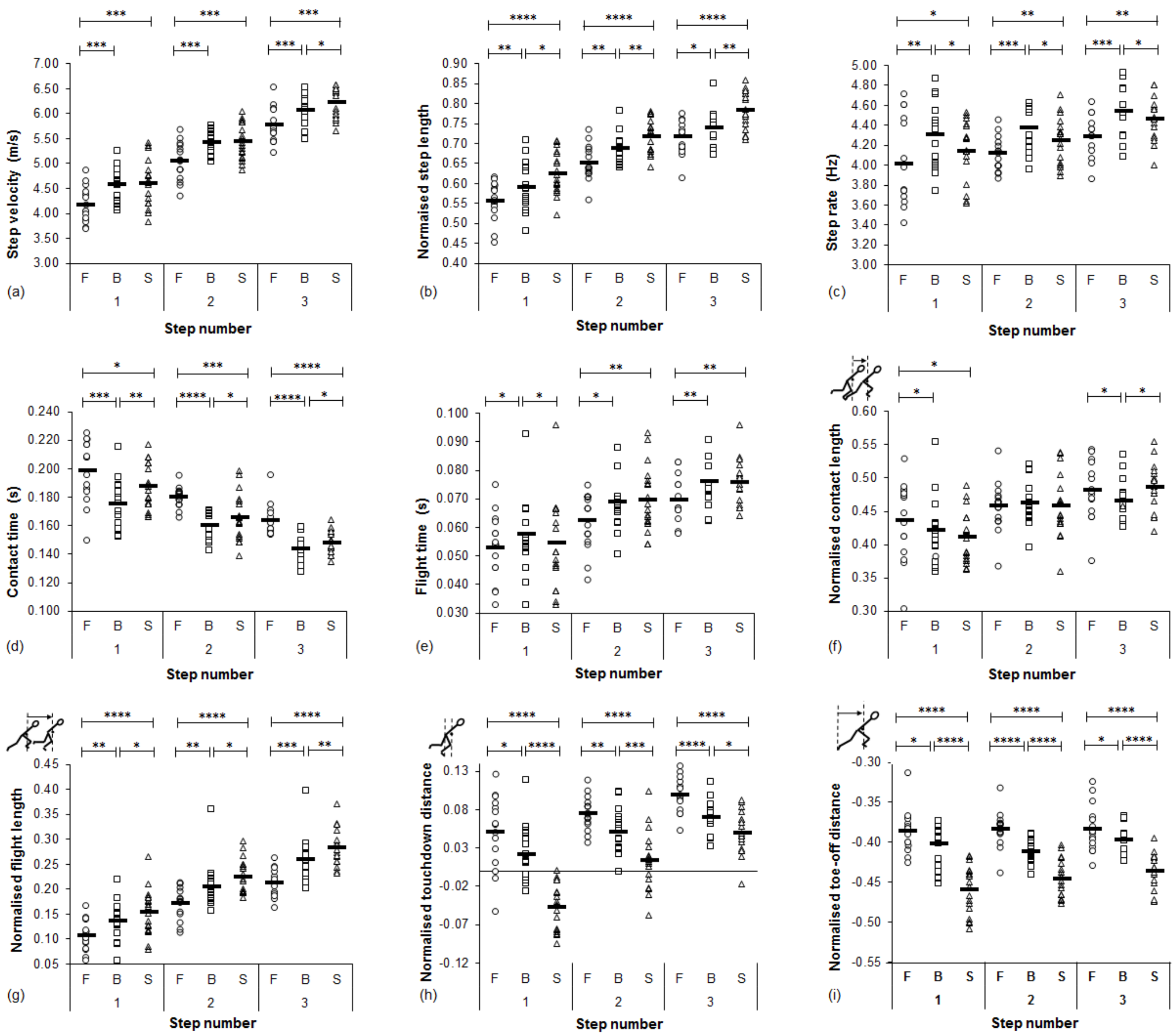

Figure 2. Step characteristics and linear kinematic variables for rugby forwards (F) and backs (B), and sprinters (S) during the first three steps of a sprint. Individual participant means are plotted, and the black bars represent group means and each participant within each group is represented as an individual data point. The number of asterisks depict the quantitative chances of finding between group differences: * = possibly; ** = likely, *** = very likely, **** = most likely

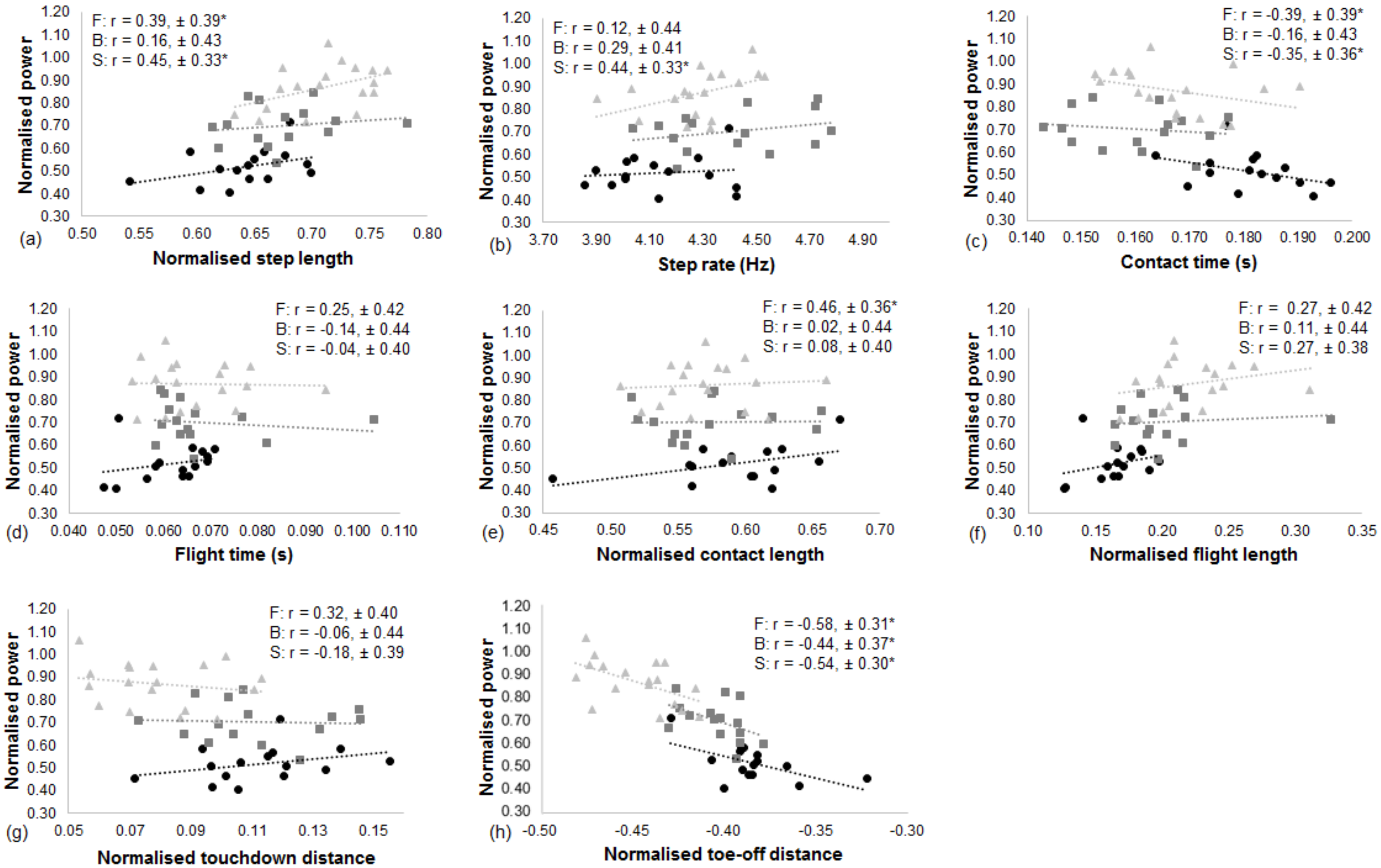

Figure 3. Relationships (Pearson's correlation coefficients and their 90% confidence intervals) of step characteristics and linear kinematic variables with average normalised average horizontal external power for forwards (F), backs (B) and sprinters (S) from first touchdown until the end of the third contact phase of a sprint. Black circles = rugby forwards; dark grey squares = rugby backs and light grey triangles = sprinters. Asterisks indicate clear relationships where confidence limits do not overlap substantial positive and negative values (i.e. r = ± 0.1; Hopkins, 2002).